Project

Solenoidal Tracker at RHIC (STAR)

Subproject

Time Projection Chamber - Assembly and Test

Title

Structural Analysis of TPC Support Arm Installation Fixture

1.0 Introduction

The TPC Support Arm Installation Fixture, fig. 1 is used to facilitate mounting of the TPC Support Arms. The fixture consists of a guide rail, a plate connecting the rail to the magnet to prevent side to side motion and a clevis mounted the magnet to resist vertical forces. A pair of struts transfer the load from the rail to the clevis. The following note contains calculations of the stresses in the most highly loaded parts. Elastic stability of the struts is also considered. An overall capacity is calculated from the allowable stresses for the materials used and applying generous safety factors.

2.0 Loads:

Weight of TPC at installation $W_{ARM} := 267\ lbf$

Weight of one installation rail, approximately $W_{rail} := 40\ lbf$

Weight trolley and mounting plate, approximately $W_{trolley} := 15\ lbf$

3.0 Struts:

As the TPC is rolled from one end of the rail to the other the weight of the trolley and the Support Arm will be directly over either strut/rail joints at some point in time. Given the struts angle wrt. the rail and their relative lengths, the worst case will occur at the junction of the strut and rail outboard from the magnet face. Assume the rail is supported equally between the two struts and mounting plate. Refer to figs.2a and 2b.

$$W := \frac{W_{rail}}{3} + W_{ARM} + W_{trolley} \qquad W = 295.333 \cdot lbf$$

Assuming that bending of the rail contributes negligibly to the vertical support of the TPC Arm as it is positioned over point 1, see Fig.4.

$$a := 25\ deg \qquad b := 60\ deg$$

$$F_A := \frac{W}{\sin(a)} \qquad F_A = 698.818 \cdot lbf$$

$F_B := F_A \cdot \cos(a)$ $\qquad F_B = 633.344 \circ \mathrm{lbf}$

$F_C := F_A \cdot \dfrac{\sin(90 - a)}{\sin(90 - b)}$ $\qquad F_C = 836.532 \circ \mathrm{lbf}$

Stress and stability of struts.

The cross section of the struts is 1.5" square. $t := 1.5\ \mathrm{in}$

Elastic Modulus $E := 10 \cdot 10^6 \dfrac{\mathrm{lbf}}{\mathrm{in}^2}$

Length $L := 50\ \mathrm{in}$

Radius of gyration $r := \dfrac{t}{\sqrt{12}}$

End coeff., round $C := 1$

Stress, axial:

worst case $\sigma_C := \dfrac{F_C}{(1.5\ \mathrm{in})^2}$ $\qquad \sigma_C = 371.792 \circ \dfrac{\mathrm{lbf}}{\mathrm{in}^2}$

Elastic stability using Euler formula for slender columns:

$$\sigma_{crit} := \frac{C \cdot \pi^2 \cdot E}{\left(\frac{L}{r}\right)^2} \qquad \sigma_{crit} = 7.402 \bullet 10^3 \circ \frac{\mathrm{lbf}}{\mathrm{in}^2}$$

Given that column buckling typically occurs well below the theoretical limit, a large safety factor must be used. For this case a safety factor of 10 will be applied.

$$\sigma_{des} := \frac{\sigma_{crit}}{10}$$

Working backwards to define a capacity for the strut gives:

$$W_{cap} := W \cdot \frac{\sigma_{des}}{\frac{F_A}{t^2}} \qquad W_{cap} = 703.869 \circ \mathrm{lbf}$$

4.0 Pins

Shear stress in bolts pinning struts to rail.

The struts are pinned to the rail via 1/2" HHCS, grade 2 or better at points 1 and 2 on fig. 4. These screws are in double shear.

Proof stress for a SAE grade 2 fastener 3/4" and below is 55,000 psi. Use one-quarter of the proof stress as the design limit. Set the allowable shear stress to 1/2 of the allowed tensile value.

Stress area: $A_s := 0.334\ \mathrm{in}^2$

The capacity limitation due to bolt shear can be determined by working backwards from the strut forces determined above.

$$F_{Aallowed} := \frac{55000\ \frac{\mathrm{lbf}}{\mathrm{in}^2} \cdot A_s}{4}$$

$$W_{Scap} := W \cdot \frac{F_{Aallowed}}{F_A} \qquad W_{Scap} = 1.941 \cdot 10^3\ \mathrm{lbf}$$

5.0 Rail

Bending stress in rail assembly.

The rail assembly consists of a commercial linear bearing guide bolted to a 4 inch wide by 3/4" thick strongback.

Dimensions of THK HSR 35CA linear rail (steel)

$$x_1 := 25\ \mathrm{mm} \qquad y_1 := 29\ \mathrm{mm} \qquad A_1 := x_1 \cdot y_1$$

Dimensions of strong back, 6061 Aluminum

$$x_2 := 4\ \mathrm{in} \qquad y_2 := .75\ \mathrm{in} \qquad A_2 := x_2 \cdot y_2$$

Calculating the area moment of inertia neglecting the mix of materials and assuming the modulus of aluminum throughout, a conservative simplification.

$$d_2 := \frac{y_2}{2} \qquad d_1 := y_2 + \frac{y_1}{2} \qquad y_1 + y_2 = 1.892\ \mathrm{in}$$

$$I_1 := \frac{x_1 \cdot y_1^3}{12} \qquad I_2 := \frac{x_2 \cdot y_2^3}{12}$$

Vertical distance from base to centroid.

$$Y_c := \frac{(A_1 \cdot d_1 + A_2 \cdot d_2)}{A_1 + A_2} \qquad Y_c = 0.633 \cdot in$$

Vertical distance to extreme fiber.

$$c := y_1 + y_2 - Y_c \qquad c = 1.259 \cdot in$$

Area moments of inertia for principal axes:

$$Ixx := I_1 + A_1 \cdot (d_1 - Y_c)^2 + I_2 + A_2 \cdot (d_2 - Y_c)^2$$

$$Ixx = 0.994 \cdot in^4$$

$$Iyy := \frac{y_1 \cdot x_1^3 + y_2 \cdot x_2^3}{12}$$

$$Iyy = 4.091 \cdot in^4$$

Treating the rail as a simply supported beam gives:

where : $L_b := 31\ in$ the approximate distance for points 4 to 2 on fig.4.

$$M := \frac{W \cdot L_b}{4}$$

$$\sigma_b := \frac{M \cdot c}{Iyy} \qquad \sigma_b = 704.421 \cdot \frac{lbf}{in^2}$$

stress under normal operating conditions

To find the capacity work backwards from the allowable stress for the 6061-T6 aluminum.

$$\sigma_{ult} := 45000 \frac{lbf}{in^2}$$

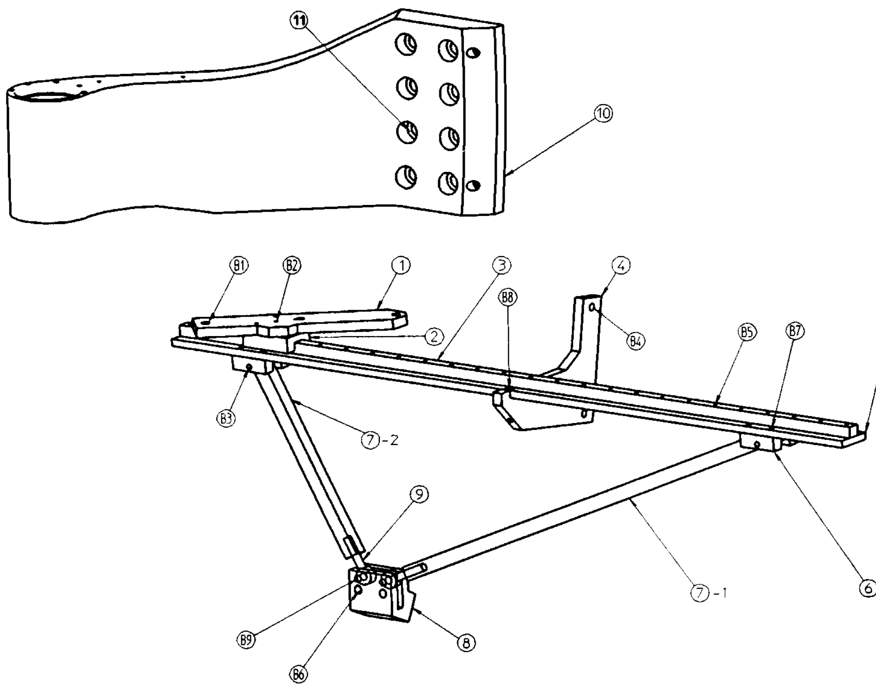
Apply a safety factor of 4 on ultimate strength.

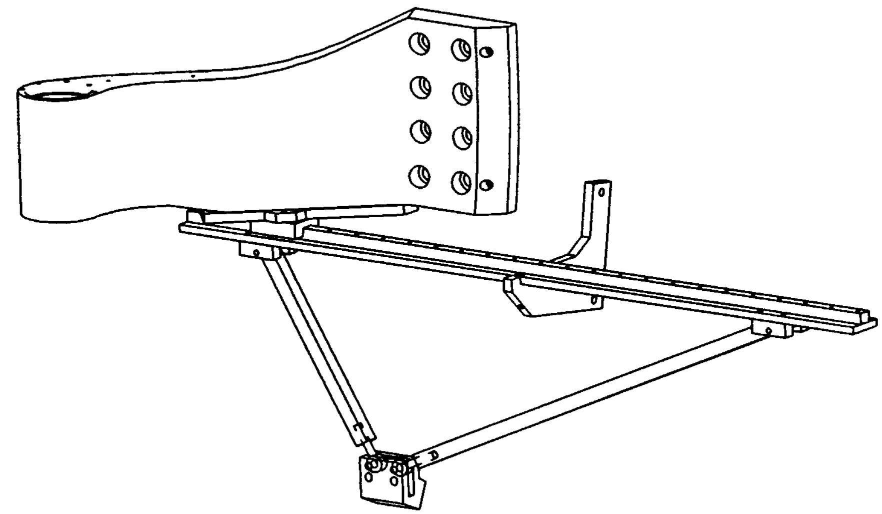
$$\sigma_{allow} := \frac{\sigma_{ult}}{4}$$

$$W_{Bcap} := W \cdot \frac{\sigma_{allow}}{\sigma_b} \qquad W_{Bcap} = 4.717 \cdot 10^3 \cdot lbf$$

6.0 Conclusions

The TPC Support Arm Installation Fixture has a large margin of safety. The weight supporting capacity of the fixture is limited by the elastic stability of the long strut to 704 lb.





ITEM	REQ	NAME/PART NUMBER	DESCRIPTION
10	4	21F 0926C	TPC SUPPORT ARM
9	2	ROD END	ROD END BEARING, AURORA #
8	1	CLEVIS.2	ALUM. PLATE, 6061T6, AS REQ.
7	1 EA	STRUT	ALUM BAR, 6061T6, AS REQ.
6	2	CLEVIS.1	ALUM. PLATE, 6061T6, AS REQ
5	1	STRONGBACK	ALUM. PLATE, 6061T6, AS REQ
4	1	FACEBRACE	ALUM. PLATE, 6061T6, AS REQ
3	1	RAIL	TDK #HSR 35CA LINEAR RAIL
2	1	BEARING	TDK #HSR 35LM LINEAR MODULE
1	1	MOUNTING PLATE	ALUM. PLATE, 6061T6, AS REQ.

ITEM	REQ	NAME/PART NUMBER	DESCRIPTION
B11	4	BOLT	H.H.C.S., STEEL, 1/2-13 UNC X 1" LONG
B10	32	BOLT	S.H.C.S., 316SS, 1 1/4-7 UNC X 5.5" LONG
B9	2	BOLT	H.H.C.S., STEEL, 3/4-10 UNC X 3" LONG
B8	2	BOLT	S.H.C.S., STEEL, 1/2-13 UNC X 1" LONG
B7	8	BOLT	H.H.C.S., STEEL, 1/2-13 UNC X 2.5" LONG
B6	2	BOLT	H.H.C.S., STEEL, 3/4-10 UNC X 3.75" LONG
B5	26	BOLT	S.H.C.S., STEEL, 5/16-18 UNC X 1.5" LONG
B4	2	BOLT	H.H.C.S., STEEL, 3/4-10 UNC X 2" LONG
B3	2	BOLT	H.H.C.S., STEEL, 1/2-13 UNC X 5" LONG
B2	4	BOLT	S.H.C.S., STEEL, 5/16-18 UNC X 2.5" LONG
B1	3	BOLT	H.H.C.S., STEEL, 3/4-10 UNC X 2" LONG

Fig.1 TPC Support Arm Installation Fixture

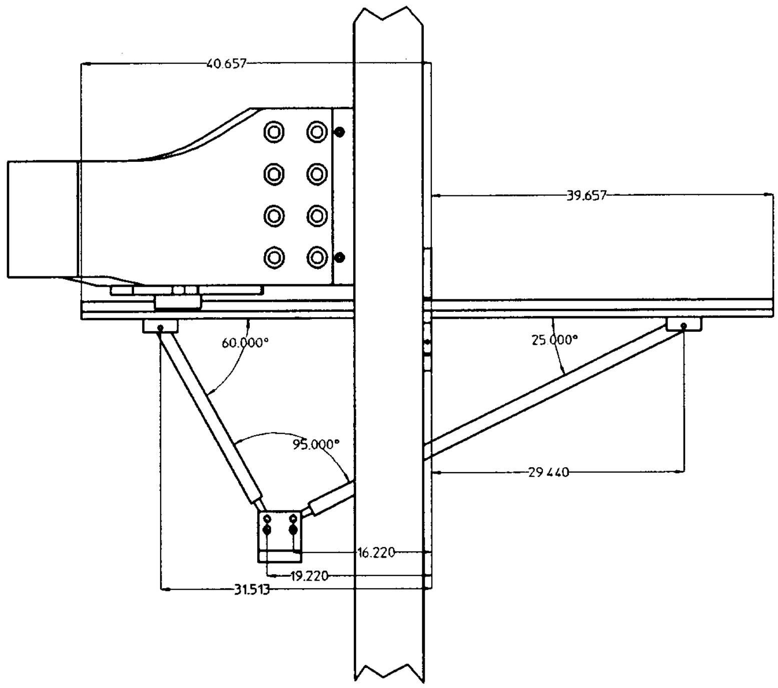


Fig.2a TPC Support Arm Installation Fixture assembled dimensions.

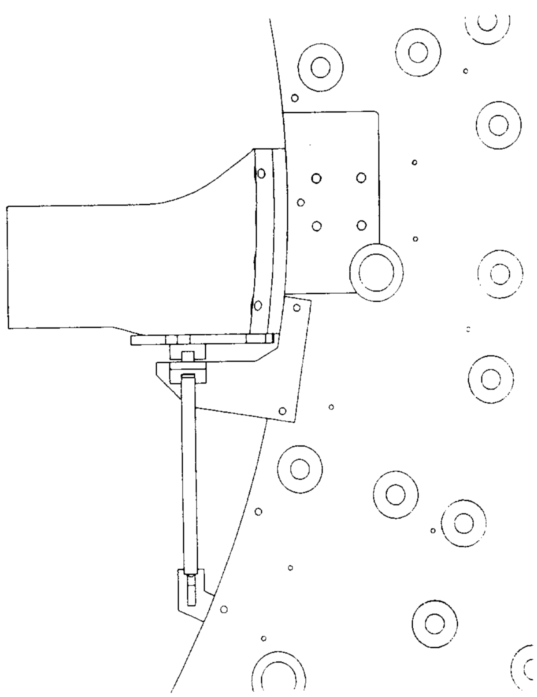


Fig.2b TPC Support Arm Installation Fixture end view.

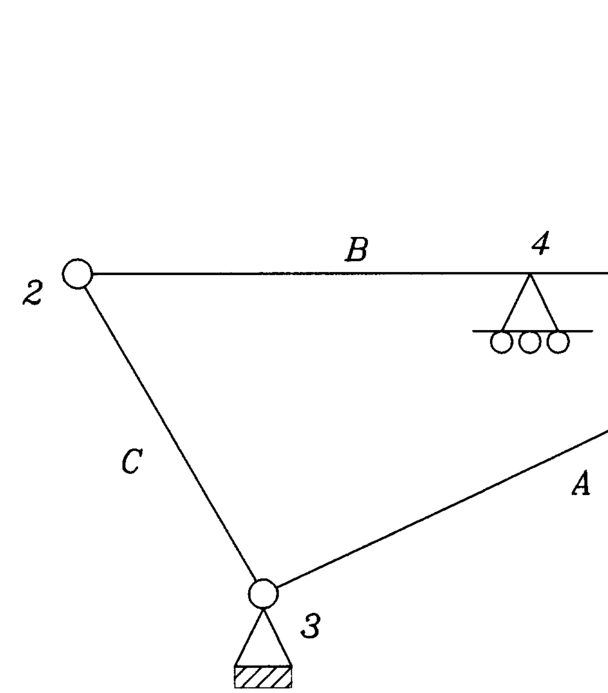


Fig. 3 Schematic representation of Arm Installation Fixture.

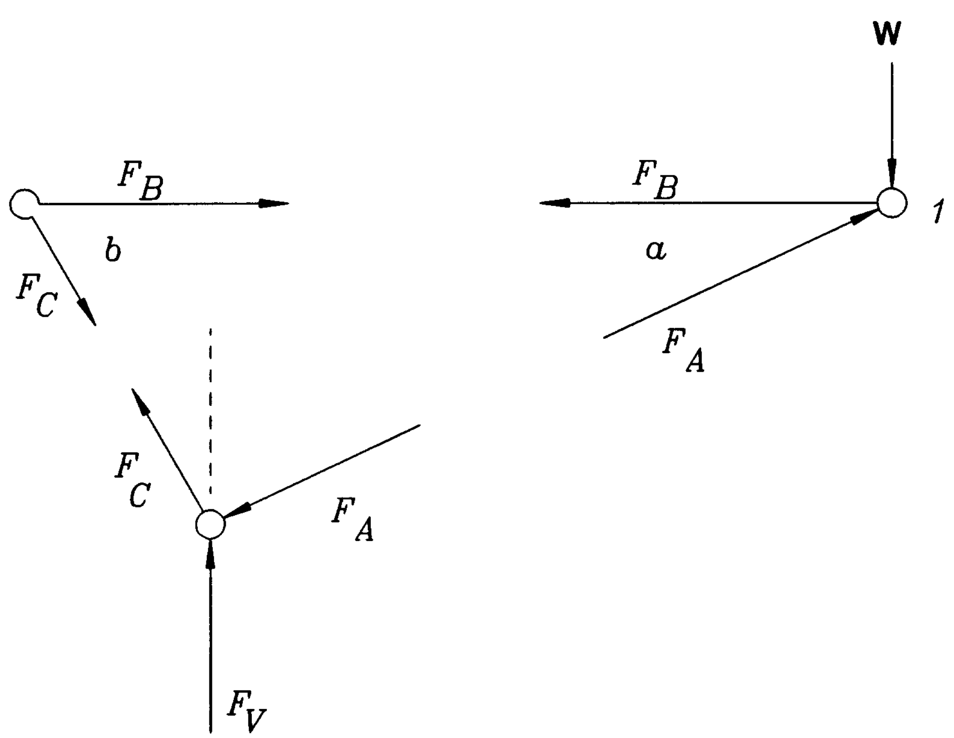


Fig. 4 Free body diagram of installation fixture.